

# MAGNETIC SUPERSYMMETRY BREAKING <sup>\*†</sup>

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## ABSTRACT

I discuss the breaking of space-time supersymmetry when magnetic-monopole fields are switched on in compact dimensions.

The breaking of space-time supersymmetry is arguably the main stumbling block on the road to superstring unification <sup>1</sup>. It raises a series of unresolved mysteries, including those of (i) the gauge hierarchy, (ii) the vanishing cosmological constant and (iii) the stability of the dilaton and moduli. The source of all these difficulties lies in the gravitational sector, whose consistency requires the presence of the entire tower of string states. It is therefore important to have breaking mechanisms that can be formulated directly at the string level. Examples of such mechanisms include the coordinate-dependent compactifications <sup>2</sup>, the anomalous-U(1) induced D-term <sup>3</sup>, and magnetic fields in compact dimensions <sup>4,5</sup>. The first two have been extensively discussed in the literature. Here I will say a few words about the latter, referring the interested reader to [5] for more details.

The simplest setting in which to discuss this mechanism is toroidal compactifications of the type-I open superstring. Consider for definiteness going from ten down to four dimensions on three 2-tori  $\mathcal{T}_a$ , where  $a=(45),(67),(89)$ . Vacuum configurations of the  $SO(32)$  gauge fields consist of Wilson-line backgrounds, as well as constant magnetic fields  $F_a$  inside the Cartan subalgebra  $U(1)^{16}$ . The magnetic fields must point in orthogonal directions in group space,

$$tr(F_a F_b) = 0 \quad \text{if } a \neq b, \quad (1)$$

in order that the three-index antisymmetric tensor  $\mathcal{H}^{MNR}$  of string theory be single-valued. They must also obey the Dirac quantization conditions

$$F_a = k_a Q_a / \mathcal{A}_a, \quad (2)$$

where  $\mathcal{A}_a$  is the area of the  $a$ th torus,  $Q_a$  an  $SO(32)$  generator normalized so that the smallest charge in the adjoint representation equals one, and the  $k_a$  are arbitrary integers. That the above backgrounds solve the tree-level equations is a peculiarity

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of open-string theory, in which gravitational (closed-string) tadpoles are postponed to the one-loop level <sup>6</sup>. The full string spectrum can be summarized by the formula:

$$\delta\mathcal{M}^2 = \sum_{a=(45),(67),(89)} (2n_a + 2\Sigma_a + 1) \epsilon_a , \quad (3)$$

where the  $n_a$  are integers labelling the Landau levels,  $\Sigma_a$  is the spin operator on the  $a$ th plane, and  $\epsilon_a$  is a non-linear function of the field  $F_a$  and of the two charges on the string endpoints. In the weak-field limit one has

$$\epsilon_a \simeq q_a k_a / \mathcal{A}_a , \quad (4)$$

with  $q_a$  the total charge of the state in the direction  $Q_a$ . We have not indicated in equation (3) the spin-independent contributions to the mass coming from Wilson-line backgrounds on the tori. These only contribute when the string state does not feel the corresponding magnetic field, i.e. when the appropriate charge  $q_a = 0$ .

The pattern of supersymmetry breaking is encoded in the mass formula (3). Notice that only the charged states are affected, and these belong to  $10d$  vector multiplets, i.e.  $N = 4$  multiplets in four dimensions. Such multiplets include a space-time vector with internal-spin assignment  $(\Sigma_{(45)}, \Sigma_{(67)}, \Sigma_{(89)}) = (0, 0, 0)$ , four chiral fermions with spin assignment  $(\pm\frac{1}{2}, \pm\frac{1}{2}, \pm\frac{1}{2})$  where the number of plus signs must be even, and six space-time scalars with internal-spin assignments  $(\pm 1, 0, 0)$ ,  $(0, \pm 1, 0)$  and  $(0, 0, \pm 1)$ . The splitting of the multiplet that follows easily from the above can exhibit two very interesting features: *chirality* and *tachyonic scalars*. The net number of massless chiral fermions is in fact a consequence of the index theorem,

$$\#chiral - \#antichiral = \prod_a k_a q_a , \quad (5)$$

and does not generically vanish. The tachyonic scalars on the other hand are a manifestation of the well-known Nielsen-Olesen instability <sup>7</sup> of non-abelian magnetic backgrounds. Their presence can trigger gauge-symmetry breaking, with appropriate reduction of the rank of the group. One can exploit these features to find simple compactifications with a classical spectrum coming remarkably close to that of the standard model <sup>5</sup>.

Whether such features can survive after all the dust in the gravitational sector settles down is unclear. Besides gravitational instabilities, the magnetic breaking shares in fact with the other stringy mechanisms one extra problem <sup>8</sup>: the splittings are proportional to the inverse size of some compact dimensions, so that one has a non-renormalizable field theory between the string and supersymmetry-breaking scales. If these scales are hierarchically different there is a risk of blowing-up coupling constants <sup>9</sup>. One possible way out of this difficulty is to have a tree-level breaking which is large but confined to a hidden hypermassive sector. The splittings then get hierarchically suppressed when transferred gravitationally to the observable sector.

This is reminiscent of gaugino-condensation scenarios <sup>10</sup>, but could be implemented with magnetic fields directly at the string level. Such a solution cannot by the way be envisaged in the context of Scherk-Schwarz compactifications which give a universal mass to gauginos <sup>2</sup>. The difficulty with the above scenario is, however, the large induced cosmological constant.

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